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December 18, 1974

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SOLID STATE ELECTRO-OPTIC COLOR FILTER AND IRIS

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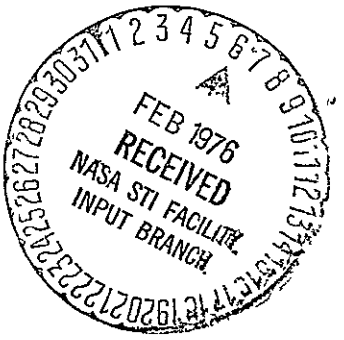
INTERIM REPORT

APRIL 1974 THROUGH NOVEMBER 1974



PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
HOUSTON, TEXAS
UNDER CONTRACT No. NAS 9-13549

RCA

RCA GOVERNMENT AND COMMERCIAL SYSTEMS
ASTRO-ELECTRONICS DIVISION PRINCETON, NEW JERSEY

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PREFACE

This is an interim report on the progress of the project "Solid State Electro-Optic Color Filter and Iris," being performed by the Astro-Electronics Division of RCA for the Johnson Space Center of the National Aeronautics and Space Administration under Contract NAS 9-13549. Wafer polishing and electrode deposition tasks were performed by the RCA Laboratories. The report covers work performed from April 1974 through November 1974, and responds to the documentation requirements set forth in Article I-34, Items 4 and 5 of the contract.

SECTION I

INTRODUCTION AND SUMMARY

The Astro-Electronics Division (AED) of RCA submits to NASA this second engineering study report covering the second phase of Solid State Electro-Optic Filter (SSEF) development under Contract No. NAS 9-13549.

The first phase of the contract covered evaluation of the electro-optic properties of PLZT ferroelectric ceramic material when utilized as a variable density and/or spectral filter in conjunction with a television scanning system. (PLZT is an acronym for a homogenous solid solution of lead zirconate and lead titanate, modified with lanthanum oxide.)

Theory of operation and general performance measurements are contained in the first engineering study report (AED R-4013F) issued May 31, 1974.

The second phase of the contract placed primary emphasis on the development of techniques and procedures for processing the PLZT disks and for applying efficient electrode structures. A number of samples were processed using different combinations of cleaning, electrode material, and deposition process. Best overall performance resulted from the direct evaporation of gold over chrome electrodes. Successful samples were produced for use in an experimental measurement program.

In addition, a ruggedized mounting holder assembly was designed, fabricated and tested. The assembly provides electrical contacts, high voltage protection, and support for the fragile PLZT disk, and also permits mounting and optical alignment of the associated polarizers.

Operational measurements of a PLZT sample mounted in the new holder assembly were performed in conjunction with a GFP television camera and the associated drive circuits developed during Phase I. Transfer curves (transmission vs. control voltage) were obtained for the finished assembly. The data verified achievement of the major objective, namely elimination of the previously observed "white-line" effect.

SECTION II

TECHNICAL DISCUSSION

A. MATERIAL PROCUREMENT

The PLZT samples used for evaluation during Phase I were supplied by Sandia Laboratories. To permit evaluation of a commercial source of supply, the new test samples were procured from Optoceram Inc.,* a company formed by Dr. Gene H. Haertling. Dr. Haertling performed initial development of PLZT material while employed at Sandia Laboratories. (Subsequent to procurement of the new samples, Optoceram was acquired as a subsidiary of the Communications Division of Motorola, Inc.).

Forty slices of PLZT material were purchased as raw blanks, 1.50 inch diameter, and 0.020 inch thick. The material is of quadratic composition 9065 (9/65/35, La/Zr/Ti ratio). The unpolished PLZT wafers received for the experiments represented samples from four production boules, identified as follows:

GH-0038-03 - (S/N 01 thru 12)

GH-0049-04 - (S/N 01 thru 08)

GH-0049-05 - (S/N 01 thru 09)

GH-0049-07 - (S/N 01 thru 11)

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*3434 Vassar N.E., Albuquerque, N. M.

Hysteresis curves and characteristic data were supplied for each of the four lots. Figure 1 shows representative data for lot 0038-03. This data is obtained by temporary attachment of evaporated aluminum electrodes by the vendor.

B. SUMMARY OF EXPERIMENTAL DESIGN MATRIX

In order to be able to distinguish, if necessary, those effects of ingot number, or position of slice in the ingot that might be superimposed on the effects of different processing procedures, the following randomized, modified Latin Square design was implemented:

The unfinished slices were designated by the supplier (Optoceram) by the serial numbers GH-0049-0X-0Y, where X = 3,4,5 or 7 designates the ingot number, and Y = 1,2,3,4 or 5 designates the slice in each ingot. Let the four processes used for fabricating the electrode patterns be designated A, B, C, D as follows:

A - Photolithographic Cr-Au
B - Photolithographic In
C - Evaporation Mask Cr-Au
D - Evaporation Mask In

The matrix of processes is shown in Table 1.

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OPTOCERAM, INC. PRODUCT DATA SHEET P.O. No. GL-FA4000-060900 F3

COMPOSITION 9065 MATERIAL TYPE PLZT - Quadratic

SERIAL NO. GH-0038-03-01 ELECTRODE TYPE Ev Aluminum

PROPERTIES

GRAIN SIZE 7.2 μm (microns)

VIRGIN DIELECTRIC CONSTANT (free, 1 kHz) 5830

VIRGIN DISSIPATION FACTOR (free, 1 kHz) 3.0 %

POLED DIELECTRIC CONSTANT (free, 1 kHz) 6170

POLED DISSIPATION FACTOR (free, 1 kHz) 4.5 %

MEMORY MATERIALS

REMANENT POLARIZATION, P_R _____ $\mu C/cm^2$

COERCIVE FIELD, E_c _____ V/mil; _____ kV/cm

PLANAR COUPLING COEFFICIENT, K_p _____

LINEAR MATERIALS

REMANENT POLARIZATION, P_R _____ $\mu C/cm^2$

COERCIVE FIELD, E_c _____ V/mil; _____ kV/cm

PLANAR COUPLING COEFFICIENT, K_p _____

QUADRATIC MATERIALS

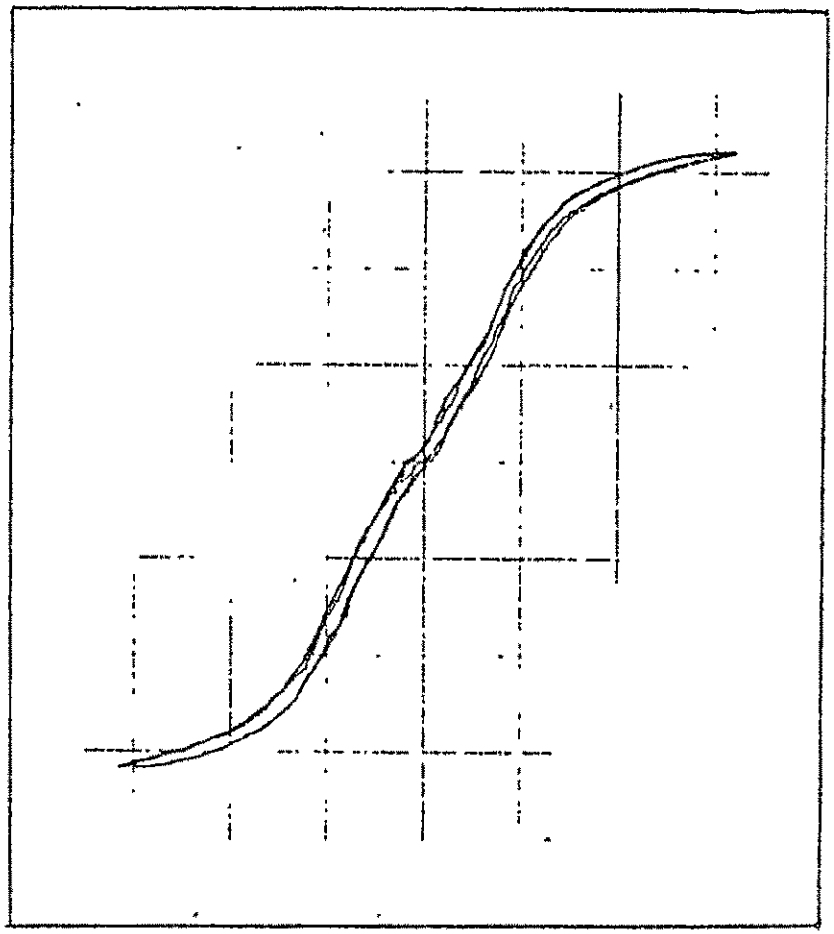
POLARIZATION AT 10 kV/cm, P_{10} 19.0 $\mu C/cm^2$

POLARIZATION AT 20 kV/cm, P_{20} 28.8 $\mu C/cm^2$

POLARIZATION AT 30 kV/cm, P_{30} 31.5 $\mu C/cm^2$

MAXIMUM SLOPE OF THE HYSTERESIS LOOP, dP/dE (max) 1.9 $\frac{\mu C/cm^2}{kV/cm}$

HYSTERESIS LOOP



X-AXIS 1 kV/inch THICKNESS 0.032 inch

Y-AXIS 1/8 μC/inch AREA 2.4 cm^2

FIGURE 1

ORIGINAL PAGE IS OF POOR QUALITY

TABLE 1. MATRIX OF PROCESSES

Y \ X	3	4	5	7
1	D	A	C	B
2	B	C	A	C
3	C	D	B	A
5	A	B	D	C

Note that the fourth slice in each ingot, Y = 4, X = 3,4,5,7 was withheld from the design. One of these slices, GH-0049-07-04 was used to fabricate photolithographically a chromium pattern for which the disk was subjected to a glow discharge prior to evaporation.

The relationship between the Optoceram and RCA Labs designations is shown in Table 2.

C. LITERATURE REVIEW

As part of the preparation for the Phase II effort on wafer polishing and electrode deposition optimization, a detailed review was conducted of existing literature sources identified during the initial program phase. Descriptions of polishing techniques, electrode materials, and electrode application methods were abstracted from the reference articles

TABLE 2. SERIAL NUMBER CROSS REFERENCE

OPTOCERAM DESIGNATION	RCA LABS DESIGNATION
GH-0049-03-01	AM-13
03-02	1
03-03	9
03-04	17
03-05	5
04-01	6
04-02	10
04-03	14
04-04	18
04-05	2
05-01	11
05-02	7
05-03	3
05-04	19
05-05	15
07-01	4
07-02	16
07-03	8
07-04	20
07-05	12

and are summarized in the following paragraphs. Reference numbers refer to the bibliography contained in the first interim technical report.

Reference 9 - Describes Fine Line Pattern Technique

1) Vapor deposit a thin layer (40 x 10^{-6} inches of 99.999% copper.

2) Dip coat dilute photoresist (Shipley AZ-111, 4:1 resist to thinner), withdraw at .8 inches per minute.

3) Air dry for one minute, oven baked at 175°F for 30 minutes (resist thickness produced is approximately 0.0001 inch). Control of thickness important to achieve close resolution etching.

4) Expose using a mylar negative in a vacuum frame.

5) Develop 3 to 4 minutes using Shipley AZ-303 developer.

6) Etch with Ferric Chloride ($Fe\ C\ell_3$) for 5 to 10 seconds.

7) Strip photoresist, using acetone.

8) Using DC Diode Sputtering of tin Doped Indium Oxide ($In_2O_3\ SnO_2$), (8 mole percent), a thin film of In_2O_3 is deposited over surface (4 x 10^{-6} inches).

9) Copper/Indium Oxide layer removed by dip in Ferric Chloride for 3 to 5 minutes.

10) Remaining Indium Oxide provides a fine line, thin line, transparent conductive pattern.

Reference 15

1) After polishing, anneal in air at 700°C for one hour to relieve strain.

2) RF sputter in a mixing gas of 50% argon, 50% oxygen at a pressure of 6 μm, using indium oxide with 9 mole % tin oxide. Deposition rate 45 Å/min. Substrate temperature about 500°C.

3) Mask with photoresist and etch in oxalic acid at 65°C. Etch rate was 38 Å/min.

Reference 16 - Discusses Aging and Switching vs. Electrode Material

1) Surface finish obtained by polishing with 1/4 μ diamond using tin laps. (Diamond grinding to near finish thickness produced strains, broke samples, and was abandoned.)

2) Anneal in air at 700°C for 10 minutes which also provides cleaning of volatile residues before electroding.

3) Vapor deposit through mask. Electrode thickness was minimum of 5000 Å.

4) Attach flying lead with air-drying silver paste.

5) Electrode materials tried were:

a. CR (300 Å) covered by Au (5000 Å)

b. Pb alone

c. Pb, oxidized 30 minutes in oxygen at 700°C, covered with Ag

d. Sn (5000 Å) covered by Ag (3000 Å)

e. Ag alone

f. Aℓ alone

g. Ga alone

h. In alone

6) Other Comments - Samples with surface contamination show rapid aging (degradation). In and Ga appeared to provide better ohmic contact than other materials. Best aging achieved with In. Suggestion made to consider graded electrodes.

Reference 42

1) Plate mounted on a holder and lapped to within 100 microns of final thickness.

2) Polish using 1 micron diamond.

3) For better finish, polish with 1/4 micron diamond, or colloidal silica (0.03 μ particles) as a finish operation.

4) Remove from holder and remount with unpolished surface exposed. Repeat lap and polish to final thickness.

5) Remove from holder, clean, anneal in air at 700°C for 10 minutes to relieve surface strain.

6) Apply aluminum or gold electrodes using metal masks and either vacuum deposition or sputtering of the electrode material.

7) Flying leads attached by thermal compression bonding of gold wire.

Reference 51 - Describes Same Basic Approach as Reference 42, With Following Differences

1) Polish to thickness using wet surface grinding techniques and SiO 600-grit sandpaper.

2) Finish polish using 1 micron or smaller diamond in distilled water.

3) For polishing, PLZT held to lava blocks using crystal bonding agent. Crystal bond removed from finished surfaces by ultrasonic cleaning.

4) Annealed at 600°C for 10 minutes.

5) Final cleaning by ion bombardment in vacuum deposition chamber.

6) Opaque Aluminum flashed onto PLZT to form electrodes.

7) Conductive paint used between electrodes and external terminals.

Reference 55

1) After polishing, anneal at 700°C for 10 minutes. Cool slowly through Curie point (330°C for 65/35-2 PLZT) to avoid thermal shock.

2) Indium electrodes evaporated onto sample.

Additionally, discussions were held with J. T. Cutchen and J. O. Harris, Sr. of the Sandia Laboratories to review their PLZT processing experience. These discussions highlighted the following facts, pertinent to our investigation.

a Deleterious electrode effects (like "white-line" phenomenon) tend to occur more with narrow than with wide electrodes.

b. Processing in general is much more difficult for two-sided electrode application. Units were frequently cracked in the alignment process.

c. Lithography difficulties experienced include etch opens, non-uniform linewidths, and surface residues after completion of photolithography.

d. Glow discharge (argon) has been tried, but it must be used with care. Since PLZT is a poor thermal conductor, it can be shattered by the induced temperature gradients.

e. There is some indication that the application of anti-reflection coatings tends to accentuate the electrode "white-line" phenomenon. Some measure of success has been achieved using RTV's as a coating agent.

f. Based on difficulties encountered with photo-lithography, they are presently concentrating on the exclusive use of direct evaporation masks. The masks used are 20 mils thick. Linewidth is 3.0 mils, and line separation (edge-to-edge) is 40.0 mils.

A common point noted from the above review is the suggestion to anneal the individual wafers subsequent to the grinding and polishing operation. This technique was included in our planned experiments. The original plan was to use photo-lithography for application of experimental electrode materials. Based on the discussions with Sandia personnel, the plan was modified to include fabrication of metal masks for electrode application by alternate direct evaporation methods. Materials selected for investigation include gold-on-chrome, and indium.

D. PLZT DISK FABRICATION PROCEDURES

Based on the literature review, and recommendations and experiments at the RCA Laboratories, detailed procedures were generated for individual processing steps. Figure 2 shows the flow diagram for the processing which is described in the following paragraphs.

1. Polish

a) Mount disks on holder with low melting-point wax.

b) Lap flat with 303-1/2 American Optical Abrasive.

c) Finish smooth with Linde A polishing compound (alumina).

d) Final polishing (chemical/mechanical) with colloidal silica (Quso or Syton)

e) Carefully remove disks from holder, clean, and re-wax with polished side against holder.

f) Repeat processes above to bring to required thickness, and finish of second side.

g) Remove from holder and clean.

2. Clean

a) Ultrasonic cleaning in room-temperature aqueous detergent solution.

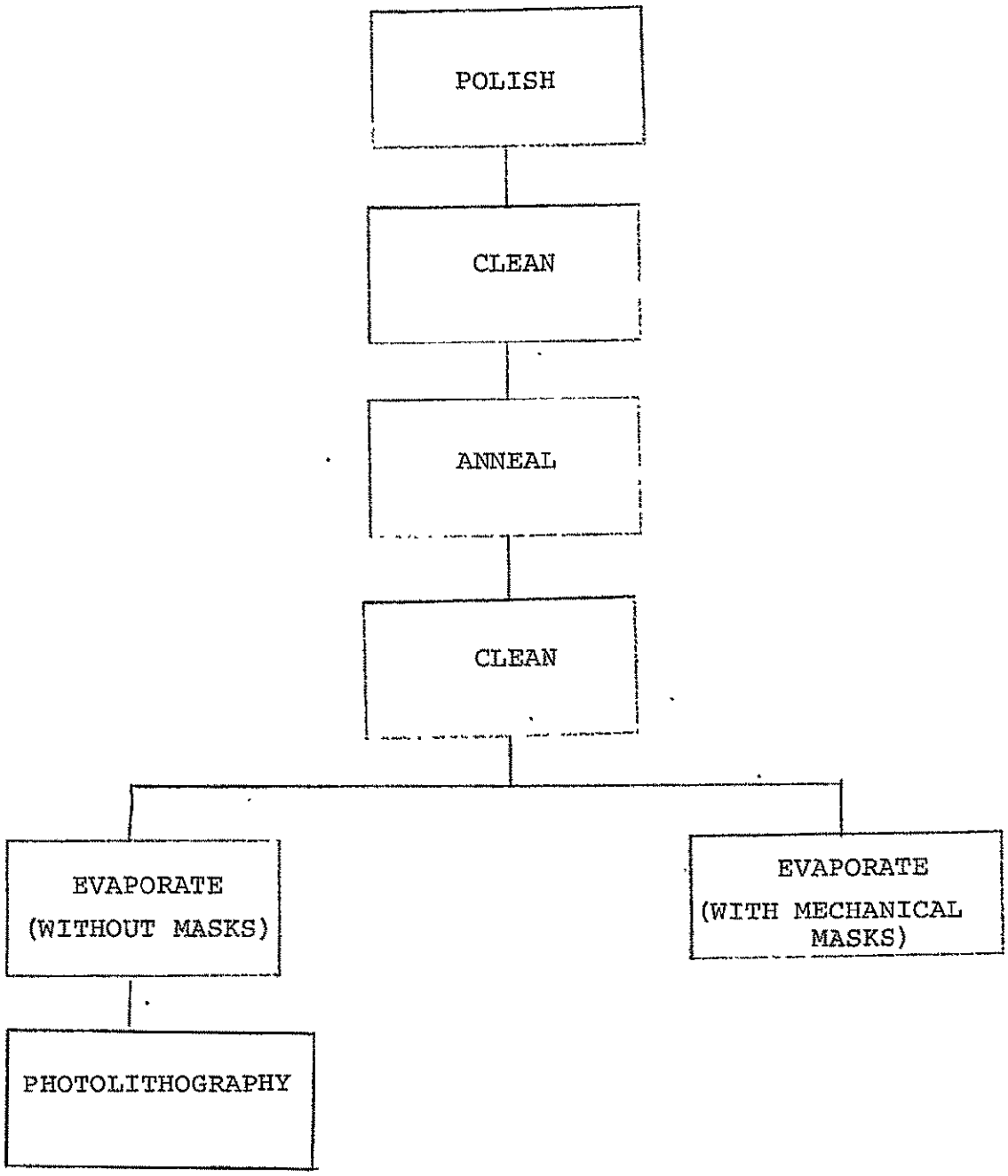


Figure 2. Processing Flow Diagram

b) Rinse in hot tap water (3-stage counter-current rinsing assembly).

c) Rinse in de-ionized water (2-stage counter-current rinsing assembly).

d) Degrease in isopropyl alcohol vapor.

3. Anneal

Heat disks to 650°C in air. Cool slowly (Programmed overnight).

4. Clean

a) Ultrasonic cleaning in room-temperature aqueous detergent solution.

b) Rinse in hot tap water (3-stage counter-current rinsing assembly).

c) Rinse in de-ionized water (2-stage counter-current rinsing assembly).

d) Degrease in isopropl alcohol vapor.

5,6. Evaporate

A. Cr-Au*

1) Evacuate to 2×10^{-6} Torr.

2) Substrates at room temperature. Rotated substrates.

3) Evaporate 200 Å Cr at ~20 Å/sec.

4) Evaporate 5000 Å Au.

B. In

1) Evacuate to 2×10^{-6} Torr.

2) Substrates at room temperature. Rotated substrates.

3) Bleed in oxygen through controlled leak to bring pressure to 8×10^{-5} Torr.

4) Evaporate 10 Å In at 2 Å/sec.

5) Turn off O_2.

Note: Mylar-backed pressure-sensitive tape was used to secure the substrates when evaporating Cr-Au through mechanical masks. The tape was removed by soaking the disks in acetone. The disks were subsequently rinsed in acetone, and subjected to an additional cleaning procedure as described in 2 above. This technique is not considered satisfactory, as it results in extra handling of the delicate disks. Also, in most cases the masks did not retain intimate contact with the PLZT disk, resulting in non-uniform width of the deposited fingers.

A modified technique using spring clips was developed and evaluated during the indium processing. The results of these samples showed significant improvement in finger width uniformity.

6) Increase evaporation rate to 30 Å/sec.

a) Evaporate 3000 Å for photolithography, or

b) Evaporate 10,000 Å with mechanical evaporation masks.

C. Cr - Glow Discharge

1) Subject disk 10 min to dc glow discharge through 5×10^{-2} Torr oxygen.

2) Evacuate to 1×10^{-6} Torr.

3) Substrate at room temperature. Rotated substrates

4) Evaporate 1000 Å Cr at ~ 50 Å/sec.

7. Photolithography

A. Disks as received from the vacuum technology lab with evaporated metal coatings are degreased in trichloroethylene vapor to remove residual contamination.

B. Disks spun at 2700 rpm:

1) Flushed, while spinning with acetone.

2) Flushed, while spinning with ethanol that has been distilled and passed through millipore filter.

3) Spun dry.

4) Apply Shipley AC1350 (positive) photoresist - 60 second spin.

5) One hour air cure.

C. Expose photoresist through photolithographic mask.

D. Develop 15 sec. in 1:1 diluted Shipley 1350 developer.

E. Oven-bake: 80°C, 30 minutes.

F. Etch away exposed metallic films.

1) For Cr-Au films:

a) Remove Au with Film Microelectronics Inc. C-35 etch (aqueous iodine-potassium iodide). Etch until Au disappears (about 1 minute).

b) Remove remaining photoresist with acetone.

c) Etch exposed Cr in aqueous potassium ferricyanide - potassium hydroxide solution (about 1 minute at room temperature).

2) For In films:

a) Etch with semiconductor aluminum etch (nitric, acetic, and phosphoric acido in water about 2.5 minutes).

b) Remove remaining photoresist with acetone.

G. Rinse and spin-dry

E. INDIUM ELECTRODE EXPERIMENTS

Performance of experimental electrodes fabricated during Phase I using a liquid metal eutectic (gallium-indium), together with comments identified in the literature review,

indicated that indium might be a good choice for experimental investigation of electrode behavior. Consequently, we attempted to establish a process suitable for fabricating electrode arrays with indium metal in contact with the PLZT, and a gold protective layer over the indium.

Initial experiments were carried out using glass substrates as test specimens. It was found that when both layers (gold and indium) were deposited by evaporation, an intermetallic compound was formed at the interface between the gold and the indium. This compound could not be removed by conventional etchants during the photolithographic process of elecrode preparation. It was decided therefore to plan to deposit the indium layer, form an electrode pattern by photolithography, and electroplate the layer of gold over the indium pattern.

Following this path, the initial thin layers of indium prepared on glass substrates were found to be electrically discontinuous. A process developed to solve the problem involved admitting a small quantity of oxygen into the vacuum system immediately prior to evaporation of the metal. A satisfactory photolithographic etchant for these films was also developed which does not affect the surface quality of the PLZT disks.

Results from the initial transfer of these techniques to PLZT disks were disappointing, in that the depositions were found to be electrically non-conductive. Contact to the electrode

lands was attempted using spring fingers with gold leaf, pin probes, and finally interfacing with Ga-In eutectic. In no case was conduction achieved.

To remedy this problem, the plan was changed to permit deposition of the total electrode thickness using solely indium (eliminating the gold over-coat). Additional samples fabricated using this technique were found to operate satisfactorily.

Following these experimental developments, sample indium on PLZT samples were prepared using both photolithography and direct mask evaporation as shown in the test matrix (Table 1). Each etched sample was found to have from two to five open electrode fingers. Examination under a microscope established that in every case this condition was due to mechanical removal of indium from the pattern, as a result of a scratch, abrasion, or etch-out. By contrast, the plates using direct mask evaporation had all electrode fingers intact.

The behavior of the indium electrodes with respect to uniformity of the electro-optic effect within each gap was tested and found to be nearly ideal (comparable to that obtained with "liquid-metal" contacts).

After removal of the electric potential, minor "white-line" effects were observed at each electrode with alternating strengths, but even the stronger effect was localized very

closely to the electrodes, and extended no more than several microns from them. Performance of both etched and evaporated indium electrodes was good, although as noted the etched plates exhibited numerous processing opens.

Another problem considered in the application of indium was in the technique to be used for attachment of external leads to the finished PLZT disk. The gold wire ultrasonic bonding is incompatible with the indium surface. Methods have been developed which utilize freshly prepared indium wire for connections to delicate elements.[1] These are intricate and somewhat difficult to employ, thus making the use of indium electrodes less desirable.

F. PERFORMANCE CHARACTERISTICS OF FABRICATED DISKS

1. Evaporation Mask Comments

Chrome-gold electrode patterns were fabricated on four PLZT disks using the mechanical masks. On some of the disks the finger width varied uniformly from one side of the disk to another, indicating that the initial fixturing was permitting the disks to tilt with respect to the masks. (The measured variations of the finger widths on three of the disks, in mils,

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1. R.D. Larabee "Fabrication of Mercury-Cadmium-Telluride Linear Imaging Arrays." RCA report CMAT-74-TR-017, July 1974.

were 4.0-14.4, 4.0-5.0, and 4.0-7.0). A modified hold-down technique, using spring clips, was used for fabricating the indium coatings through the mechanical masks. The variations in finger widths for the indium-coated disks were found to be considerably less than those listed above, namely 4.1-4.6, 3.9-3.9, 4.1-4.3, and 3.9-4.9. It should be mentioned that outside the fairly well-defined edges of the indium fingers there was a brownish coloration that extended diffusely for perhaps half a mil. This is possibly a scattering effect due to the fact that the indium coatings require evaporation in the presence of an appreciable pressure of oxygen.

The actual masks were fabricated by an outside vendor using electroforming techniques. New master artwork on glass plates was generated to prepare the masks, using the basic dimensions of the original mask set. The electroforming process causes the finished finger width to grow by about 1 mil, hence the evaporated electrodes are slightly wider than planned.

2. General Performance Characteristics

We have observed that the concentration and size of light-scattering centers within the disks are the only properties that can be correlated with the hot-pressed pellet from which the disk was sliced. The electro-optic behavior seemed to be determined more or less completely by the electrode fabrication process. Other factors that can affect the electro-optic

behavior are described later. In the initial evaluations we made what were mostly qualitative observations to evaluate performance and to ascertain that the behavior of similarly processed disks was essentially uniform. We then selected one disk fabricated by each process, and have performed extensive quantitative measurements of their electro-optical behavior.

On disk AM-7, which has photolithographically fabricated chrome-gold electrodes, measurements were made of the birefringence at one point on the disk as a function of applied voltage. Birefringence measurements were made with a Berek compensator. Considerable hysteresis of the birefringence was observed for increasing and decreasing voltages. Similar behavior was found with the other disks measured. With 500 volts applied to the disk, the variation of birefringence with distance from the edge of the electrode was measured. Similar measurements were made on disk AM-3, which has photolithographically fabricated indium electrodes. This disk was also used to make measurements of the variation of electro-optic affect with wavelength. This was done by measuring the birefringent retardation at fixed applied voltage with various optical interference filters inserted into the system. A knowledge of the wavelength variation is necessary for the analysis of various SSEF color filter scheme.

Since the program plan for the ruggedized assembly was to bond the electroded surface of the PLZT plate to an elastomer, it was considered of interest to know whether any substance may be contacted to the electroded surface without degrading the device performance. Pieces of Scotch "magic brand" plastic tape were pressed onto the electroded surface of a photolithographic indium disk so that the adhesive was bonded to the surface. No degradation of the response uniformity or residual birefringence was found, and there was no measurable discontinuity in the electro-optic response across the edge of the tape.

Measurements of birefringence versus voltage and position were also made on disk AM-19, which was subjected to a glow-discharge cleaning step before evaporation of a chromium film, and which underwent photolithographic processing. It was at this point that the first unexpected discovery of environmental effects on the operation of these devices was observed. Initial qualitative observations indicated that this device performed rather poorly with respect to spatial uniformity of the electro-optic effect and freedom from residual birefringence. Nevertheless, when this disk was re-examined one week after the initial observations its performance was found to be superior with respect to these characteristics, i.e., comparable to what we have observed with indium and liquid-metal electrodss. Further experiments confirmed the influence of surface and ambient humidity as responsible for the observed performance variations. The vacuum encapsulation procedures planned for

the bonded holder will ensure low humidity content during the final assembly of finished devices, thus eliminating this performance variable.

Measurements of birefringence versus voltage and position were made on disk AM-11, which has a chrome-gold electrode pattern fabricated by direct evaporation through mechanical masks. The similarly fabricated disks with indium electrodes were investigated qualitatively. All electrode fingers of all of the plates fabricated by direct evaporation were found to be intact. The performance of all of these plates was degraded by the presence, after application and removal of an electric field, of numerous birefringent spots, mostly disjoint from the electrodes, similar to what we have observed previously on photolithographic chrome-gold plates. Nonuniformities in response were observed in the brownish-colored regions, described previously, of the indium disks. It was found nearly every time a directly evaporated (mechanical mask) plate was studied, irregular patches of birefringence several millimeters in size (i.e., extending over many electrode spacings) developed. These were found to be caused by the disks becoming stuck to the glass setter plates used to support the disks. Newton's rings arising from near contact of the disks to the glass plates were observed. In some cases it was necessary to "float" the disk off the plate by admitting a layer of ethanol under the disk. In order to avoid this nuisance, strips of teflon-backed

adhesive tape approximately 5 mils thick were stuck to the setter plates in order to support the disks out of close contact with the glass. When the disks were operated supported in this fashion, the small birefringent spots we had previously observed were absent. The birefringent spots are believed to be due to particles (dust?) being attracted electrostatically from the glass plate to the disk (even though the former had been cleaned) and perturbing the electric field distribution on the latter. Plates that are operated out of contact with the setter plates in a low-humidity ambient were found generally to perform quite well. The three directly-evaporated chrome-gold plates (AM-10, 11, 12) exhibited nonuniform behavior and residual birefringence only in very narrow regions at the edges of the electrodes.

G. RUGGEDIZED MOUNTING HOLDER DESIGN

1. Objectives

The SSEF mount is required to provide a space qualifiable interface between the PLZT wafer and a housing as part of a camera or lens assembly.

Several problem areas identified during the first phase of the program were investigated. They are:

- Mechanical attachment to wafer.
- Electrical attachment to wafer.
- Breakdown protection between electrodes.
- Strain free support to wafer.

In the current phase of the program an arrangement has been designed which should overcome the previously identified problems.

2. Design Description

Figure 3 shows the general arrangement for the SSEF holder. The housing is a phenolic disc, split in half and bored to accept the polarizer and analyzer. The analyzer section locates in the polarizer section. The polarizer and analyzer discs are bonded in their respective sections using RTV 560 silicone compound. The inner cavity in the polarizer section of the housing radially locates the separate PLZT assembly shown in Figure 4; the PLZT is located radially in the support disc and is attached to the support by the weld wires and Kovar fingers.

Electrical contact to the filter is by gold plated Kovar fingers located adjacent to the electrode contact surface (Figure 5). Direct electrical contact is provided by .025 mm (.001") gold jumper wires ultrasonically welded between the electrode pad and the fingers, as shown in Figure 5. The finger tabs are attached to external terminals on the polarizer section (see Figure 3). The wending process is a qualified procedure used routinely in microelectronic fabrication at RCA-AED. It offers the advantage of redundant connections in a small area, and little or no mechanical strain by virtue of the flexibility of the gold wires.

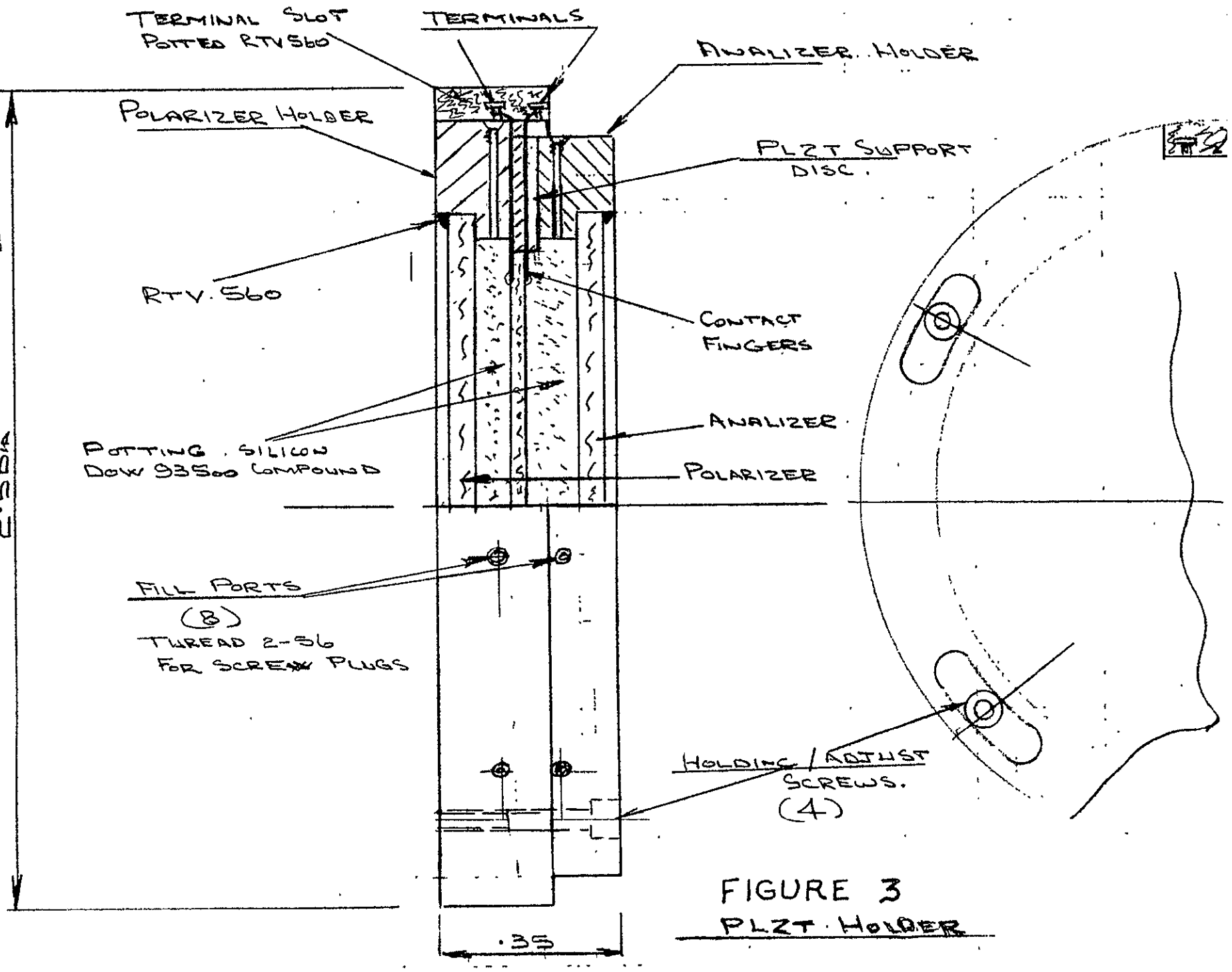


FIGURE 3
PLZT HOLDER

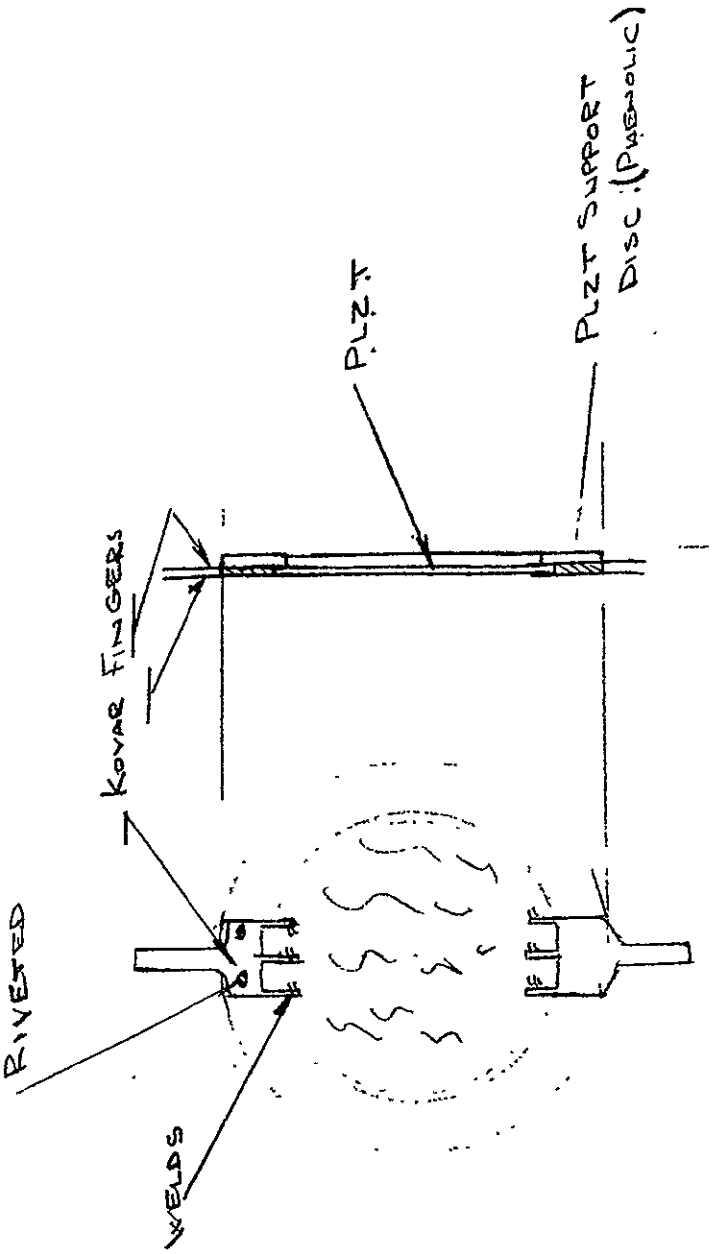


FIGURE 4 PLZT ASSEMBLY

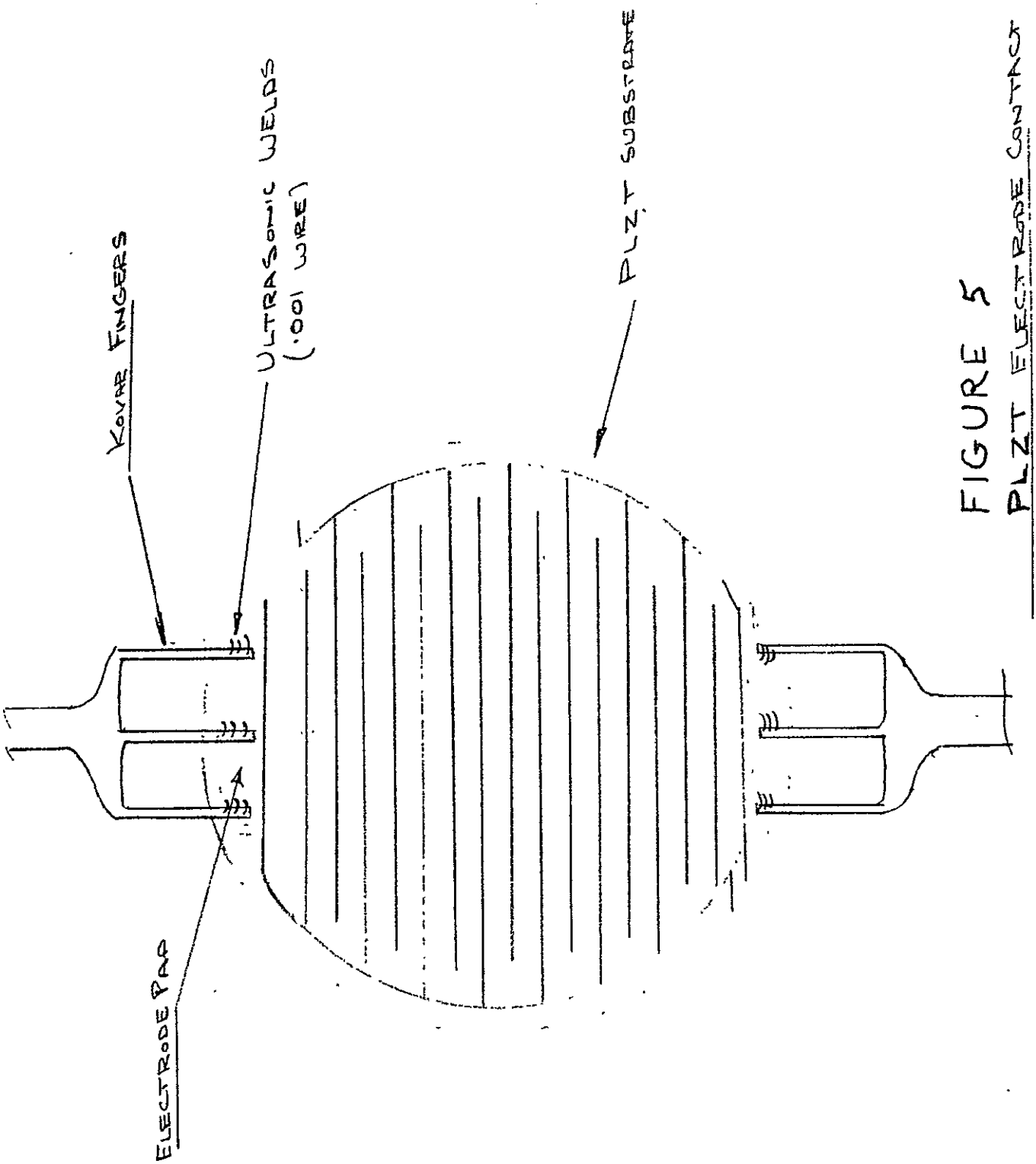


FIGURE 5
PLZT ELECTRODE CONTACT

The three pieces which comprise the holder are rotatable up to 10° for final alignment and verification of optical axes prior to potting.

Following assembly and test, the cavities which surround the PLZT disc are filled with silicone rubber Dow Corning 93-500 compound under vacuum. The encapsulant provides strain free mechanical support for the disc while providing electrical breakdown protection. The potting medium is optically transparent and has essentially a flat response in the visible spectrum. Pertinent characteristics, abstracted from the vendor data sheet, areas follows:

- Total weight loss after 24 hours at 125°C and 10^{-6} torr, less than 0.35%.
- Dielectric strength, 570 volts/mil, tested in accordance with ASTM D 140.
- Index of refraction, 1.43.
- Operating temperature range, -65°C to +200°C.
- Room temperature cure characteristic in 24 hours, without exotherm.

This particular encapsulant has been used previously in other space applications (e.ge., encapsulation of the 2000 volt power supply in the Return Beam Vidicon Cameras). Its optical properties make it a logical choice for the problem at hand.

The pertinent engineering drawings for the constituent pieces and assemblies are as follows:

SK 2273410-1	Finger Contact
SK 2282385-1	PLZT Support Disk
SK 2282386-501	PLZT Support Assembly
SK 2283896-1	Polarizer Holder
SK 2283897-1	Analyzer Holder
SK 2284259-501	PLZT Holder Assembly

Copies of the individual drawings identified above are contained in Section III.

3. Performance Data

Performance characteristics of the finished assembly were evaluated in several different areas, as follows:

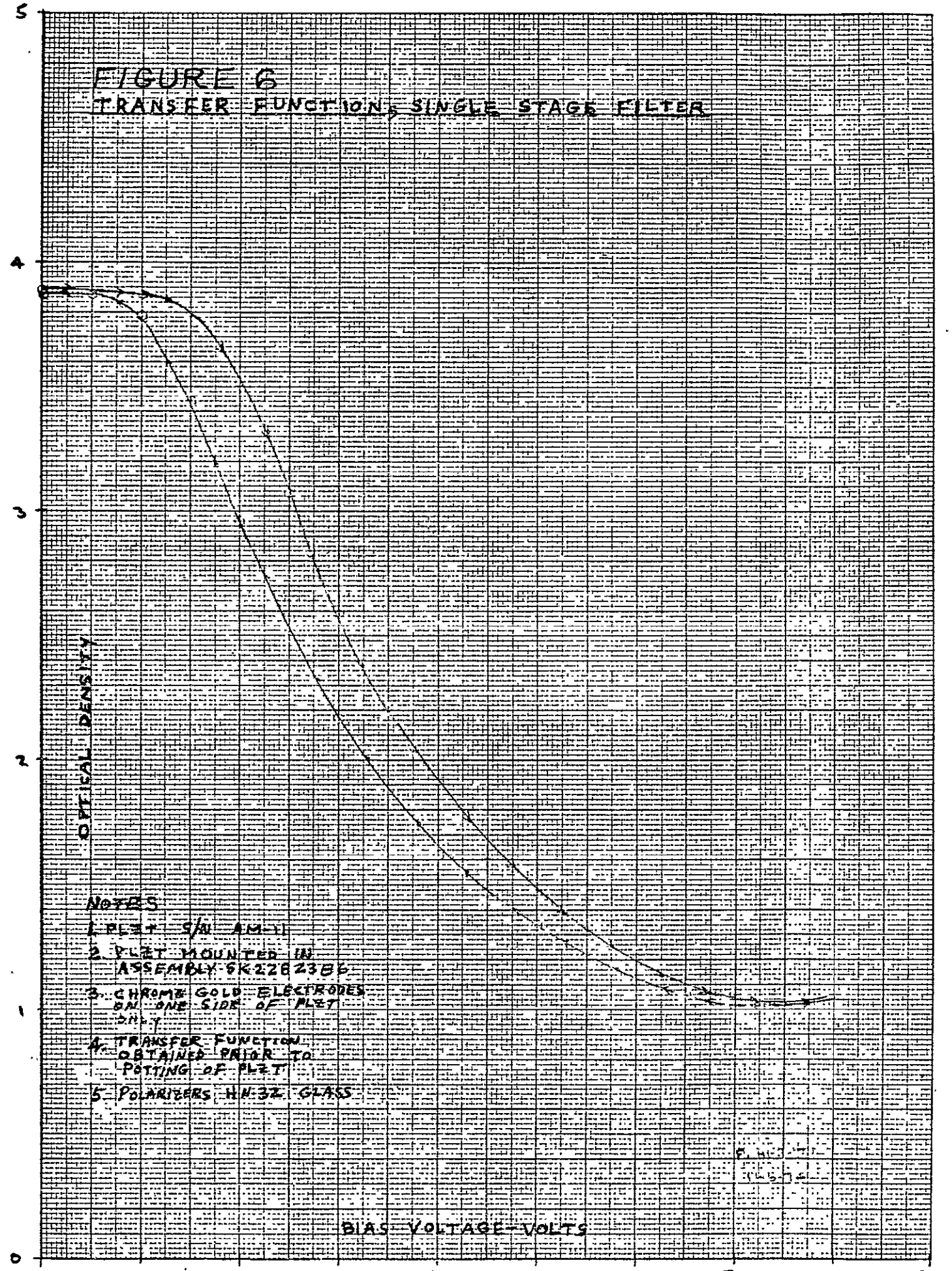
- Voltage vs. density transfer function for increasing and decreasing control voltage.
- Interelectrode capacitance.
- Open and closed loop control range in conjunction with the QTV-9 television camera.
- Photographs of electrooptic uniformity over the range from zero volts to the point of voltage breakdown.

Figures 6 and 7 respectively show the resultant transfer curves for the assembly prior and subsequent to the encapsulation with 93-500. The results are nearly identical, with the small improvement after potting attributable to the reduced reflection loss - as a result of replacing the air gap between the polarizer and PLZT with 93-500 (index of refraction 1.43 vs. 1.0). Retracing the curve several times showed no tendency to separate the end point closure (as had been seen on the Phase I filters). This is a direct result of eliminating the "white-line" remanent birefringence problem. Further confirmation of the improvement is shown in the full field photographs in a later section.

The interelectrode capacitance was measured using the step voltage technique developed during Phase I, and confirmed by substitution of an equivalent value capacitor. A value of 0.015 μfd was obtained which agrees quite closely with the average value of 0.016 μfd obtained on the original lot during Phase I.

The filter assembly was then installed between the lens and sensor of the QTV-9 television camera used for evaluation during Phase I. Control range was checked using both manual adjustment of the SSEF voltage and automatic control using the camera ALC detector in a closed loop manner. Adjustment of effective light level was accomplished using inconel coated neutral density filters in the optical path. Dynamic range in both the manual mode and automatic mode was essentially identical

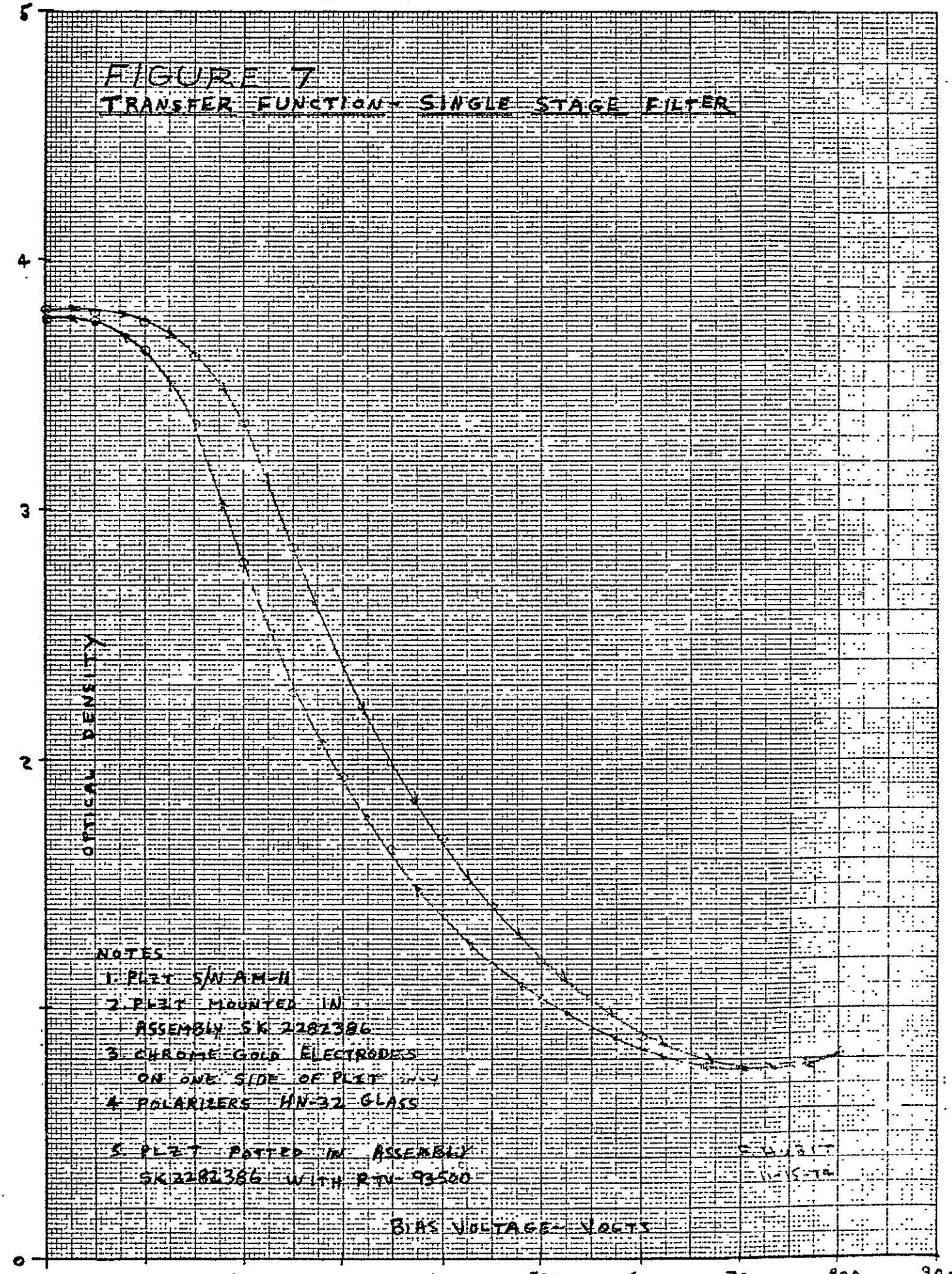
FIGURE 6
TRANSFER FUNCTION, SINGLE STAGE FILTER



NOTES

1. PLATE S/N AM-1
2. PLATE MOUNTED IN ASSEMBLY 8K22823B6
3. CHROME GOLD ELECTRODES ON ONE SIDE OF PLATE ONLY
4. TRANSFER FUNCTION OBTAINED PRIOR TO POTTING OF PLATE
5. POLARIZERS HN-32 GLASS

FIGURE 7
TRANSFER FUNCTION - SINGLE STAGE FILTER



NOTES

1. PLATE S/N AM-11
2. PLATE MOUNTED IN ASSEMBLY SK 2282386
3. CHROME GOLD ELECTRODES ON ONE SIDE OF PLATE
4. POLARIZERS HN-32 GLASS
5. PLATE POTTED IN ASSEMBLY SK2282386 WITH RTV-93500

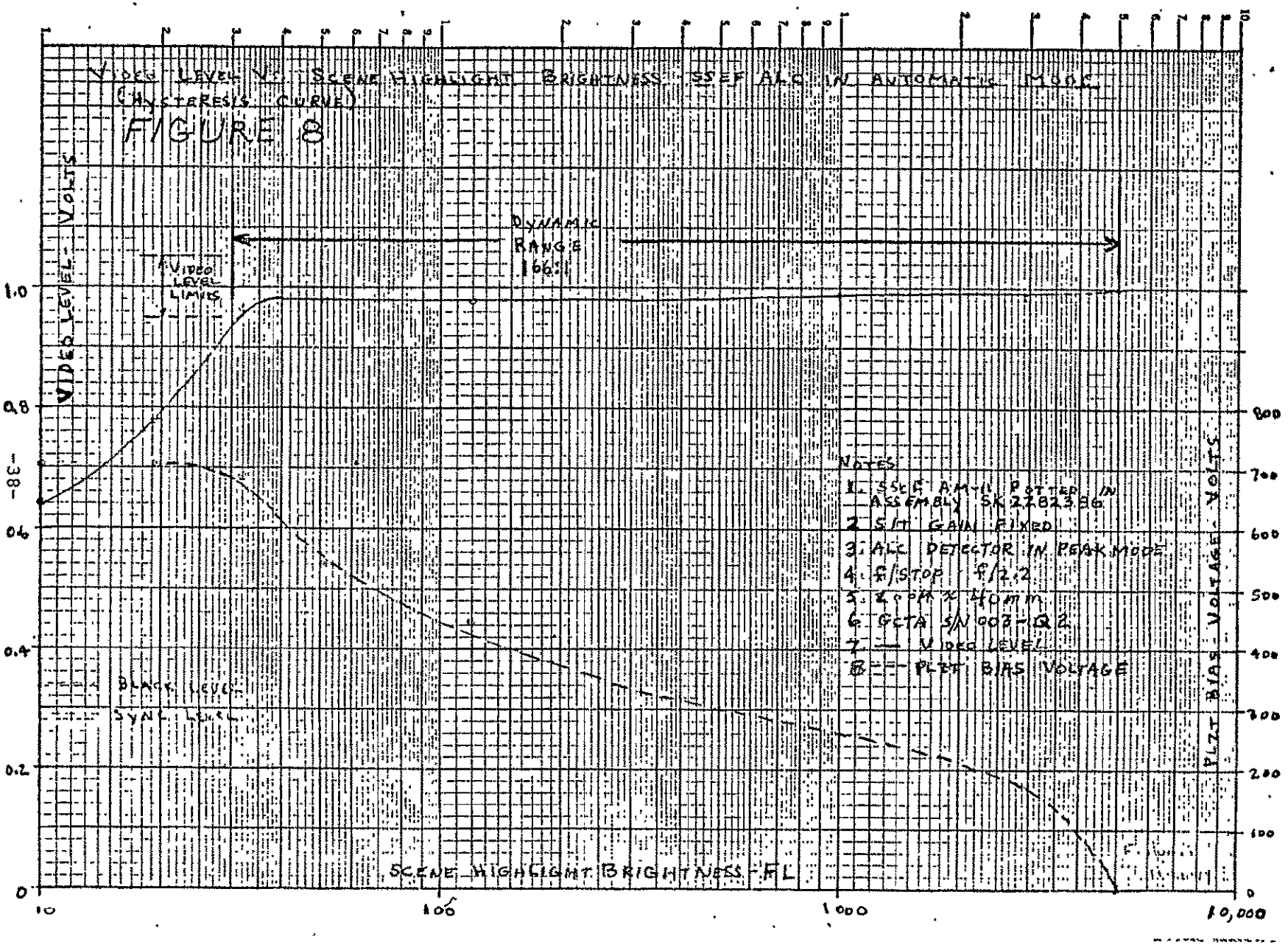
identical and measured approximately 170 to 1. Figure 8 shows the control characteristic and effective camera output.

The range obtained was somewhat less than the original transfer curve prediction (density range from 0.78 to 3.8, or 1000:1). Reference data was obtained over the range of lens focal length as follows:

Focal Length	Control Range
12.5 MM	227:1
40 MM	185:1
75 MM	156:1

Previously measured degradation of dynamic range as a function of angle of incidence would suggest some other mechanism responsible for the scale compression. Since an IR. stop filter was used in the rear exit port of the lens, out-of-band response was ruled out as a cause. The exact mechanism could not be determined, however, the range that was obtained is still well in excess of the 100:1 typically available with a conventional lens iris.

For the last test, the holder assembly was installed in the optical bench and full field photographs obtained as the applied voltage was varied. General appearance throughout the neutral density control range (0 to 700V) was excellent, as shown in the typical photograph in Figure 9 (applied potential of 400V).


VIDEO LEVEL VS. SCENE HIGHLIGHT BRIGHTNESS SSE ALC IN AUTOMATIC MODE
(HYSTERESIS CURVE)
FIGURE 20
VIDEO LEVEL - VOLTS
PLZT BIAS VOLTAGE - VOLTS
SCENE HIGHLIGHT BRIGHTNESS - FL
DYNAMIC RANGE 66:1
VIDEO LEVEL LIMITS
BLACK LEVEL
SYNC LEVEL
1.0
0.8
0.6
0.4
0.2
0
800
700
600
500
400
300
200
100
10
100
1000
10,000
NOTES:
1. SSE A.M-1 PLOTTED IN ASSEMBLY SK 27823-36
2. SIT GAIN FIXED
3. ALC DETECTOR IN PEAK MODE
4. F/STOP f/2.2
5. ZOOM X 40mm
6. GCTA S/N 003-R2
7. — VIDEO LEVEL
8. - - PLZT BIAS VOLTAGE

Continued increase of voltage potential produced the second order color results shown in Figure 10 (800V) and Figure 11 (1500V). Note from these figures that the color mode exhibited a radial distribution of uniformity, however the electrode interfaces are relatively free of distortion. The radial distribution is believed to be due to compression stress around the periphery of the PLZT disk. For later units we plan to provide increased clearance between the perimeter of the disk and its mounting holder.

When the voltage was increased beyond 1700V, arcing occurred at the surface of the PLZT disk (between the electrodes, at the interface with the 93-500 elastomer. The arcing resulted in the rupture of several electrodes and no further data was taken with this sample. Later inspection indicates that the 93-500 failed to achieve an actual bond to the PLZT ceramic surface, thus permitting an interface void and subsequent arcing. We have identified several potential surface primer materials which can be used to ensure an actual bond to the ceramic surface. The optimum one will be selected and incorporated in a new assembly.

H. ELECTRO-OPTIC COLOR FILTER

Theoretical considerations related to spectral filter application of the electro-optic effect achieved with PLZT disks were contained in the first interim technical report. We discuss further here the practical aspects of such an application.

Figure 9. 400V Full Field Photograph

Figure 10. 800V Full Field Photogrpah

Figure 11. 1500V Full Field Photograph

There are a number of methods by which the solid-state electro-optical filter could be used to provide electrically variable color response for television and other applications. In one of these methods, a single filter element is switched between two discrete states, and the spectral response of the array is thereby correspondingly switched. In the ideal limit, the two spectral responses are complements of each other (i.e., the sum of the two transmission factors is unity at each wavelength). There is considerable latitude in the choice of the complementary spectral responses, because they can be determined by a passive optical network using synthesis techniques that we have described in previous reports. One possible spectral response

is to have unit transmission for the shortest-wavelength third of the visible spectrum, and zero transmission for the remaining two-thirds. The switched state of this filter would have zero transmission for the shortest-wavelength third and unit transmission for the remaining two-thirds of the visible spectrum. Such a filter could be operated optically in series with a second filter that could be switched from unit transmission for the longest-wavelength third and zero transmission for the remaining two-thrids of the visible spectrum, to the complementary response. The four possible switched states of this pair of filters are separate transmission of each third of the visible spectrum, and zero transmission. The overall system would thus operate as an electrically controlled color separation filter. The advantage of this system is that it requires only two active elements, used as binary state switches, driven only to the half-wave retardation potential. Diagramatically, this mode is shown in Figure 12.

The ideal responses described above could be achieved if the PLZT plate could be made to behave as a 180° phase retarder for all visible wavelengths (i.e., an achromatic half-wave plate). The actual behavior of the SSEF plates differs from this, and would therefore provide less than ideal performance. Extent of the practical degradation has not been calculated.

Another approach to color filtering is to vary the spectral response by continuously varying the signal applied to the

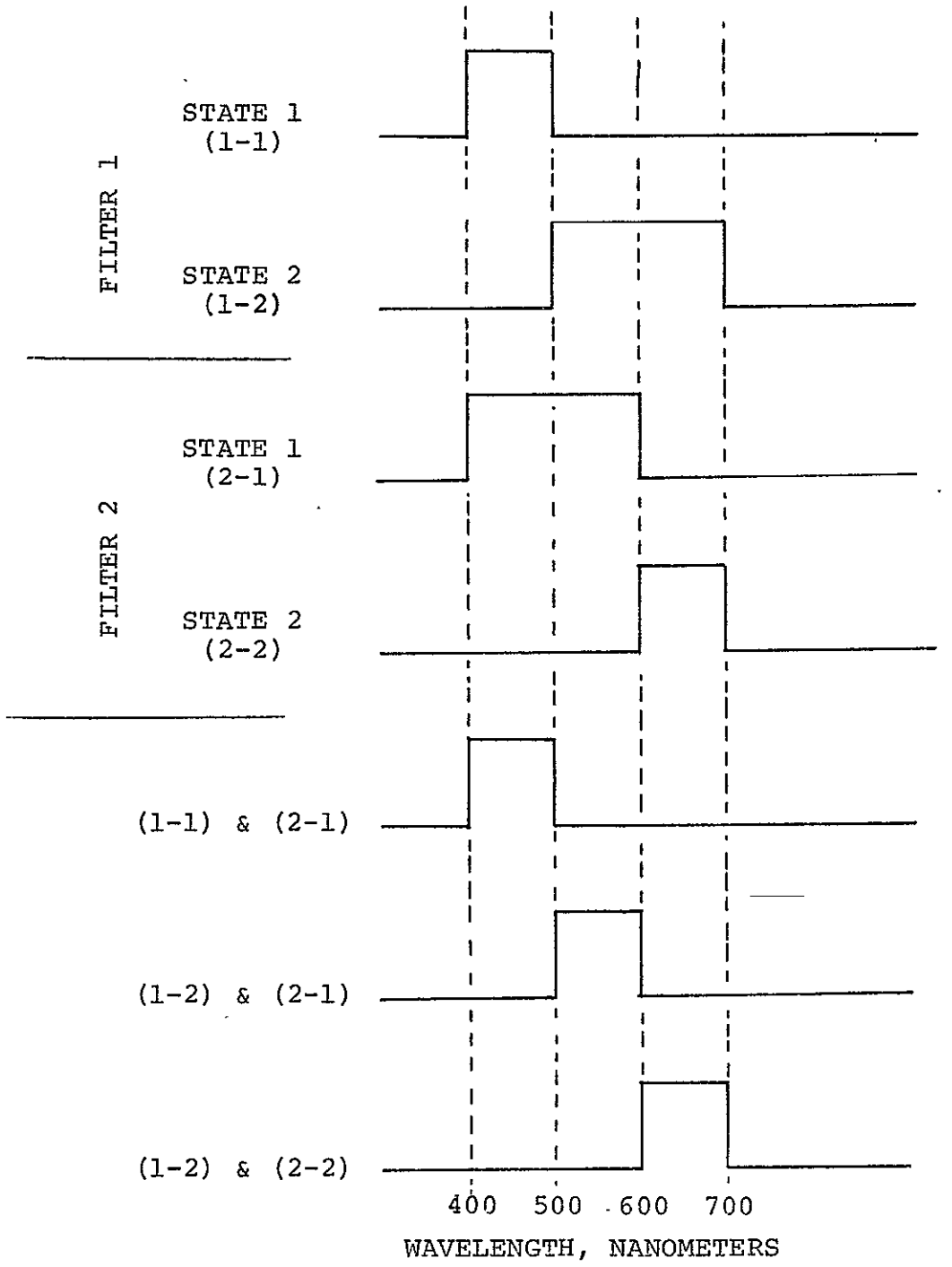


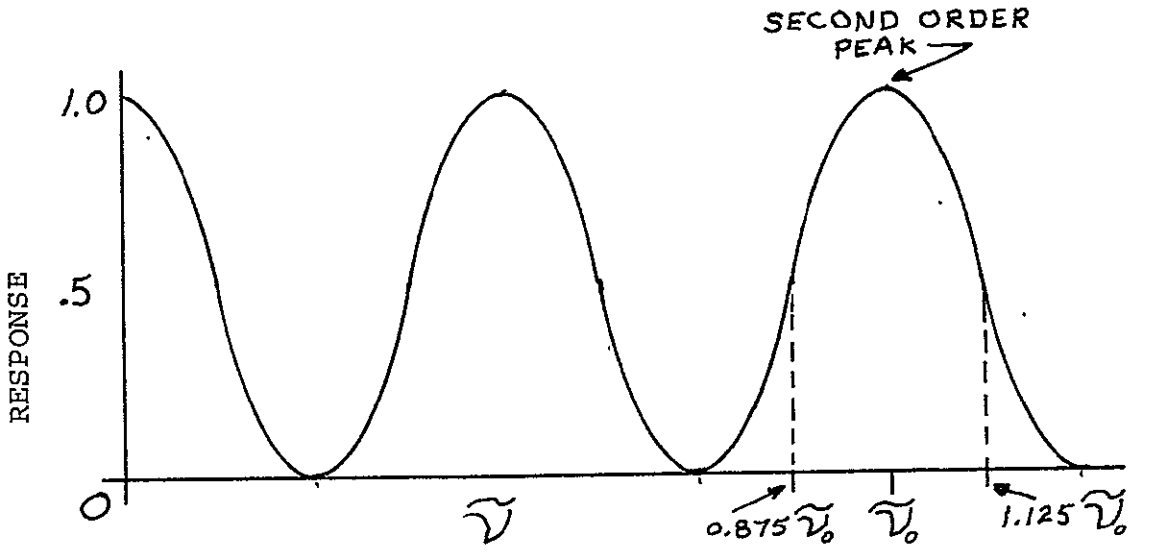
Figure 12. Idealized Cascaded Filter Operation

active SSEF element. Three configurations that could be used as color filters are discussed below. The range of birefringent retardation required to traverse the "spectrum" was determined for each of the three cases by subjective observations of interference colors using the polarizing microscope and Berek compensator. The full-width at half-height (fwhh) of the principal transmission peak, expressed as a percentage of the wavelength at peak transmission, was determined theoretically, as shown in Figure 13.

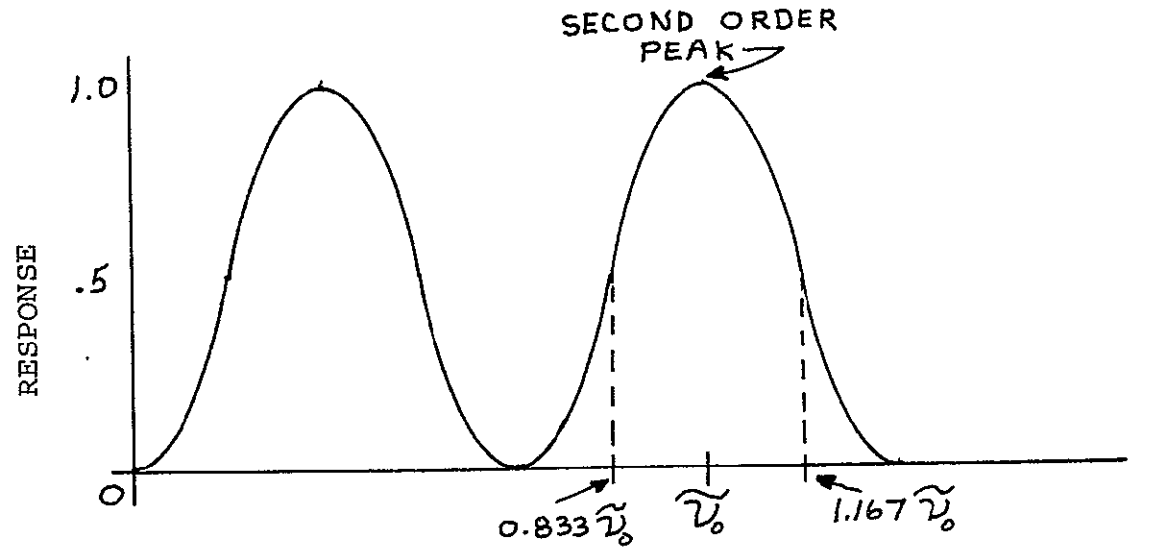
a) Configuration 1 - Simple birefringent element between crossed polars, operated in second order: Total required retardation range 561-1068 nm, fwhh = 33.3%.

b) Configuration 2 - Simple birefringent element between parallel polars, operated in second order: Total required retardation range 835-1359 nm, fwhh = 25.0%.

c) Configuration 3 - Optical network with two active birefringent elements: Total required retardation range 835-1359 nm for each elemnt. This configuration was calculated and plotted during Phase I. The half-power points are estimated from these plots to be 5/8 as far apart as for the simple parallel polarizer case. Therefore, the full width at half height is ~ 5/8 x 25, or 15.6 percent.



A. SECOND ORDER COLOR BETWEEN PARALLEL POLARS



B. SECOND ORDER COLOR BETWEEN CROSSED POLARS

Figure 13. Second Order Color Spectral Bandwidth

Note that in, for example, the last two cases, 835 nm of the required retardation for each element could be provided by a passive birefringent plate, and the remaining retardation, variable from 0 to 524 nm could be provided by an SSEF plate.

We investigated methods for incorporating the required fixed retardation (3/2 λ at 550 nm). Several techniques are known, as discussed in the following paragraphs:

a) Utilizing the birefringent property of quartz crystal, a polished slice approximately0.003" thick provides 1/2 λ retardation. The fragility of such a thin slice suggests the possibility of increasing the thickness by multiples of full wavelength. Thus, for example, a plate twenty-one 1/2 waves thick (0.063") would behave like a 1/2 λ plate at its design center wavelength. The drawbacks to this arrangement are:

   1) Temperature sensitivity is 21 times that of a true 1/2 λ plate.

   2) Retardation is exactly 1/2 λ only at the design wavelength.

b) Another method is to use two plates with a retardation difference equal to the desired value, mounted with their axes crossed (e.g., 10 1/2 λ and 11 λ for 1/2 λ plate). The problem with this arrangement is the

sensitivity to angle of incidence, since at normal incidence the two plates subtract, while at off-axis incidence, they subtract.

c) A third method is to use thin sheets of mica to provide the retardation. A 1/2 λ plate is approximately 0.008" thick. The major drawback here is the inherent light loss, since such a plate has a transmission of about 70%.

d) A fourth technique is to use special thin plastic sheets which have been stretched to render them birefringent. These sheets are relatively inexpensive, but may suffer from long term instability. We would propose to use the plastic plate method for initial experimentation, to verify the design approach.

For the final design retardation plates, we recommend using technique a) above, with addition of supporting the fragile plate by attaching it to a supporting glass plate using an optical cement.

I. CONCLUSIONS AND RECOMMENDATIONS

Based on the observed performance, the following comments can be made about the effects of the different electrode fabrication processes on the operation of the plates. Ratings of two different types can be made: (1) the performance of

plates under "good" operating conditions (low ambient humidity and out of contact with the glass setter plate), and (2) the resistance to degradation under "poor" operating conditions. Under "good" operating conditions the plates all performed quite well with regard to uniformity of response and absence of residual birefringence. In this respect the photolithographic chrome-gold arrays performed a little more poorly, and the photolithographic indium arrays performed perhaps a little better, than the other arrays. The directly-evaporated indium arrays performed a little more poorly because of the non-uniformities associated with the colored regions previously described.

As far as the tolerance of the plates to "poor" conditions, although no really controlled experiments were performed, it seemed that disks with indium and liquid metal (gallium-indium eutectic) electrodes always gave rather good results, even in ambients for which other disks gave poor results. Potentially the best performance can probably be obtained from the photolithographically fabricated indium arrays. However, because the metallic deposit on these arrays is quite thin, and because indium is very soft, these arrays exhibit poor resistance to abrasion. All of the disks made by this process have had a number of open electrode fingers. On the other hand, the patterns fabricated by evaporation through mechanical masks using either electrode material have had all fingers intact. Part of this difference in behavior may be due, however to the fact that the fingers on these disks are wider than those on

the photolithographically fabricated disks. The wider finger width is not fundamental to the direct evaporation process. The original photo-produced master artwork was examined and found to be of correct dimensions (nominally 2.5 mil line width). The metal aperture mask slit widths were somewhat wider, and approached the width of the fingers deposited on the PLZT disks. Since the only expected negative aspect of this increased width is a slight reduction in transmission, no change in the masks is planned.

There is one other facet of the use of indium which was considered. That is the difficulty associated with attachment of external leads. Techniques are known which are capable of providing a flying lead attachment to an indium surface; however, they require the use of indium coated wire, generally prepared immediately prior to use. This is an awkward and cumbersome procedure, and is not considered desirable.

Based on measurements, performance, and conclusions, the recommended procedure to be used for fabrication of additional PLZT disks is the direct evaporation (through a mask) of chrome-gold.

Performance of the finished disks prepared using mask evaporation and gold on chrome electrode material showed that the original objective of eliminating the "white line" effect was achieved.

With regard to the bonded holder assembly, the basic approach has been shown to satisfactorily protect the PLZT disk. Further improvement is required to increase the point at which surface voltage breakdown occurs. Preliminary investigation indicates this can probably be achieved by interposing a surface "primer" between the disk and the 93-500 elastomer to ensure a true bond rather than just surface contact.

J. ENGINEERING DRAWINGS

The engineering drawings generated for the bonded holder assembly are contained in the following pages.

The drawings tabulated on Page 33 are not contain in this copy, but are available from the AED print file.